



Investigation of nonlinear bulk viscoelasticity in complex media using dynamic acoustoelasticity

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Introduction

- ❖ Few tools have been developed for industrial quality control of textures. The use of non-contact techniques, based on acoustic waves, offers obvious advantages in food-processing or cosmetics industries : health & safety, non-destructive testing, continuous inline measurement.
- ❖ The Dynamic AcoustoElastic Testing (DAET) assesses the nonlinear viscoelastic properties of materials in response to a bulk compression/expansion stress. In this study, we present several applications of DAET method in complex media.

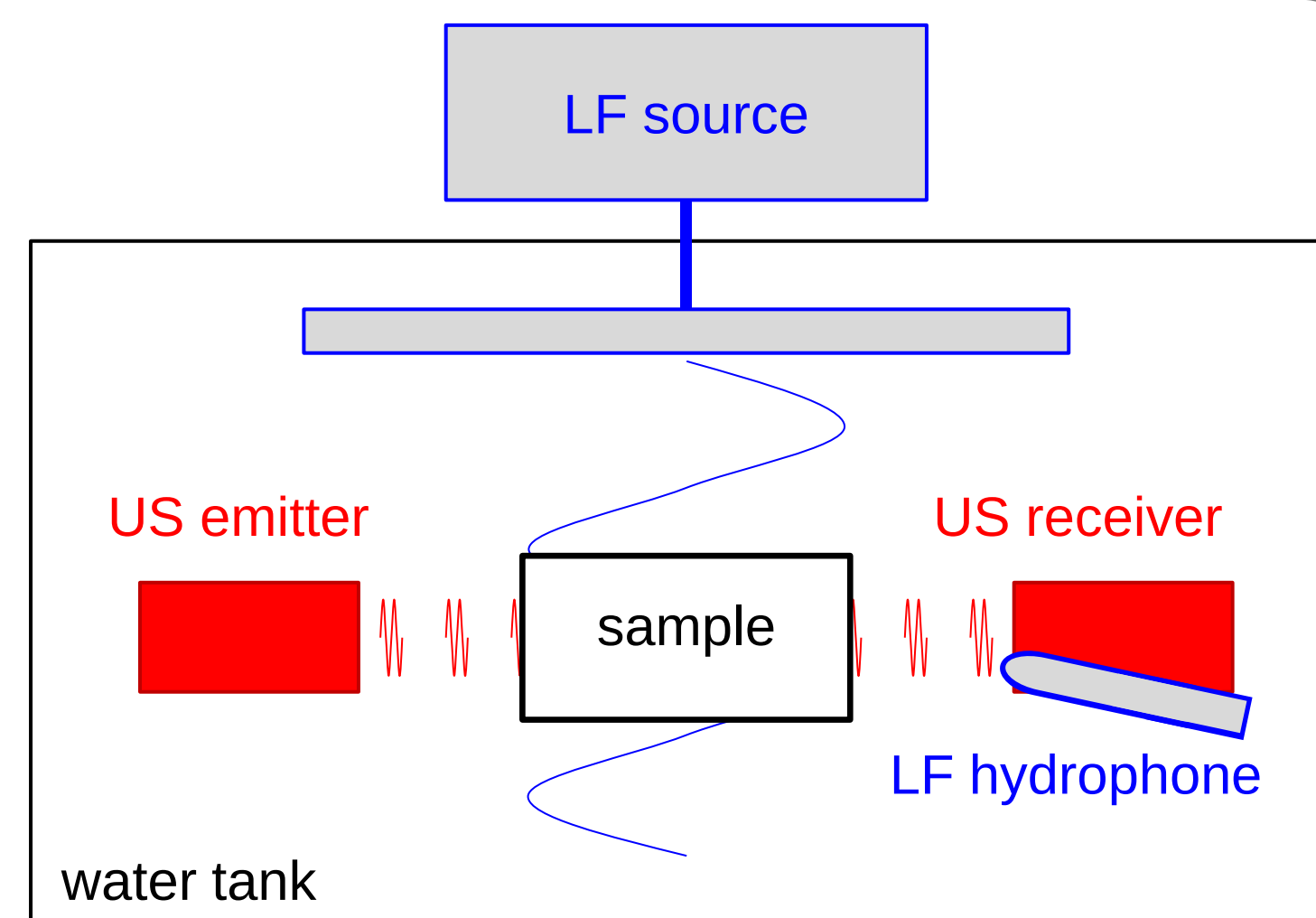
Keywords:

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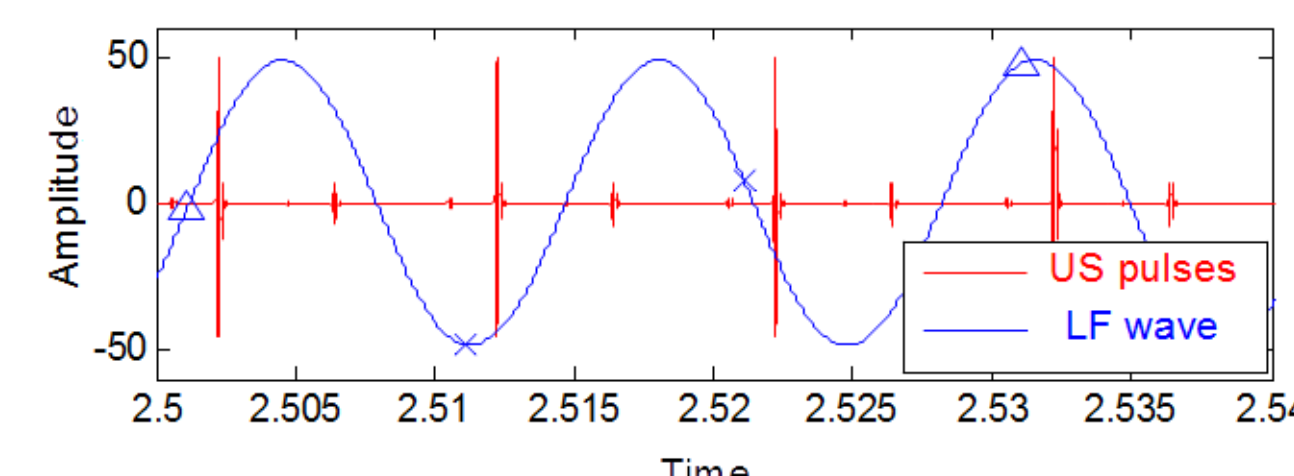
DAET method

- ❖ Interaction between two acoustic waves :

- Low-frequency sinusoidal wave (LF, 4kHz) to successively compress and expand the medium,
- Ultrasound longitudinal pulses (US, 1 MHz) to probe this medium at different pressure values imposed by the LF wave.

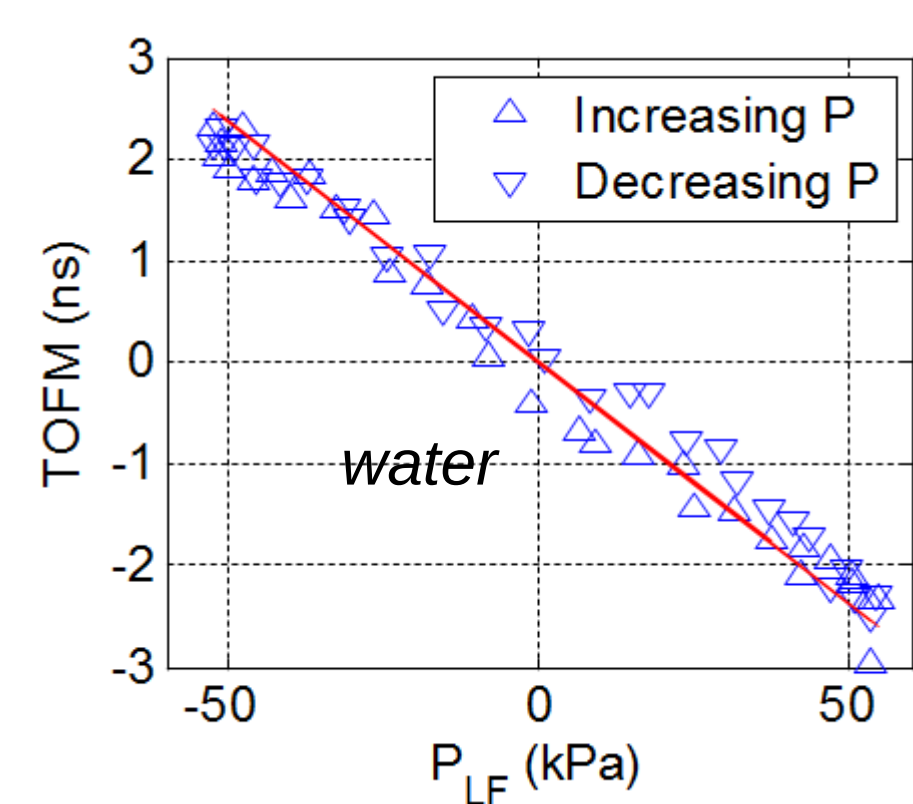


DAET synopsis



Acquired signals

- ❖ Measurement of the Time of Flight Modulations (TOFM) of the US pulses, induced by the variations of the applied LF pressure: $TOFM = TOF_{P_{LF}} - TOF_0$



- ❖ **DAET diagram:** plot of TOFM as a function of LF pressure

$$\Rightarrow TOFM^* \approx -\frac{L}{c_0^2} \Delta c^* \approx -\frac{L}{2\rho_0 c_0^3} \Delta M^*$$

with c the celerity, L the length propagation, ρ the density and $M^* = \rho c^2$ the complex longitudinal modulus

Nonlinear viscoelastic parameters

- ❖ $M^* = A^* - B^* \varepsilon + C^* \frac{\varepsilon^2}{2} - \dots$
 $\Rightarrow \Delta M^* = -B^* \varepsilon + C^* \frac{\varepsilon^2}{2} - \dots = -(B + j\omega\eta_B) \varepsilon + (C + j\omega\eta_C) \frac{\varepsilon^2}{2} - \dots$
- ❖ From the measured TOFM, we identify nonlinear viscoelastic parameters:

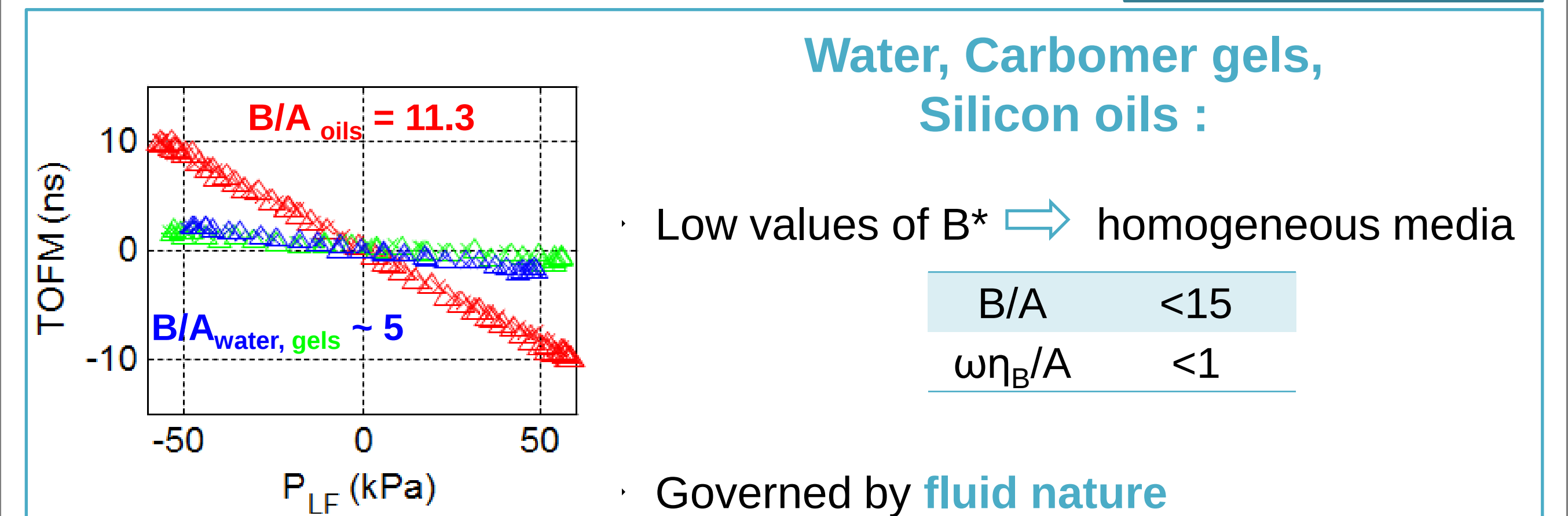
$$TOFM = -\frac{L}{2\rho_0 c_0^3} \text{Re} \left\{ \left(\frac{B}{A} + j \frac{\omega\eta_B}{A} \right) \Delta P + \left(\frac{C}{A} + j \frac{\omega\eta_C}{A} \right) \frac{\Delta P^2}{2A} \right\}$$

Elastic parameters (B/A , C/A)

Viscous parameters ($\omega\eta_B/A$, $\omega\eta_C/A$)

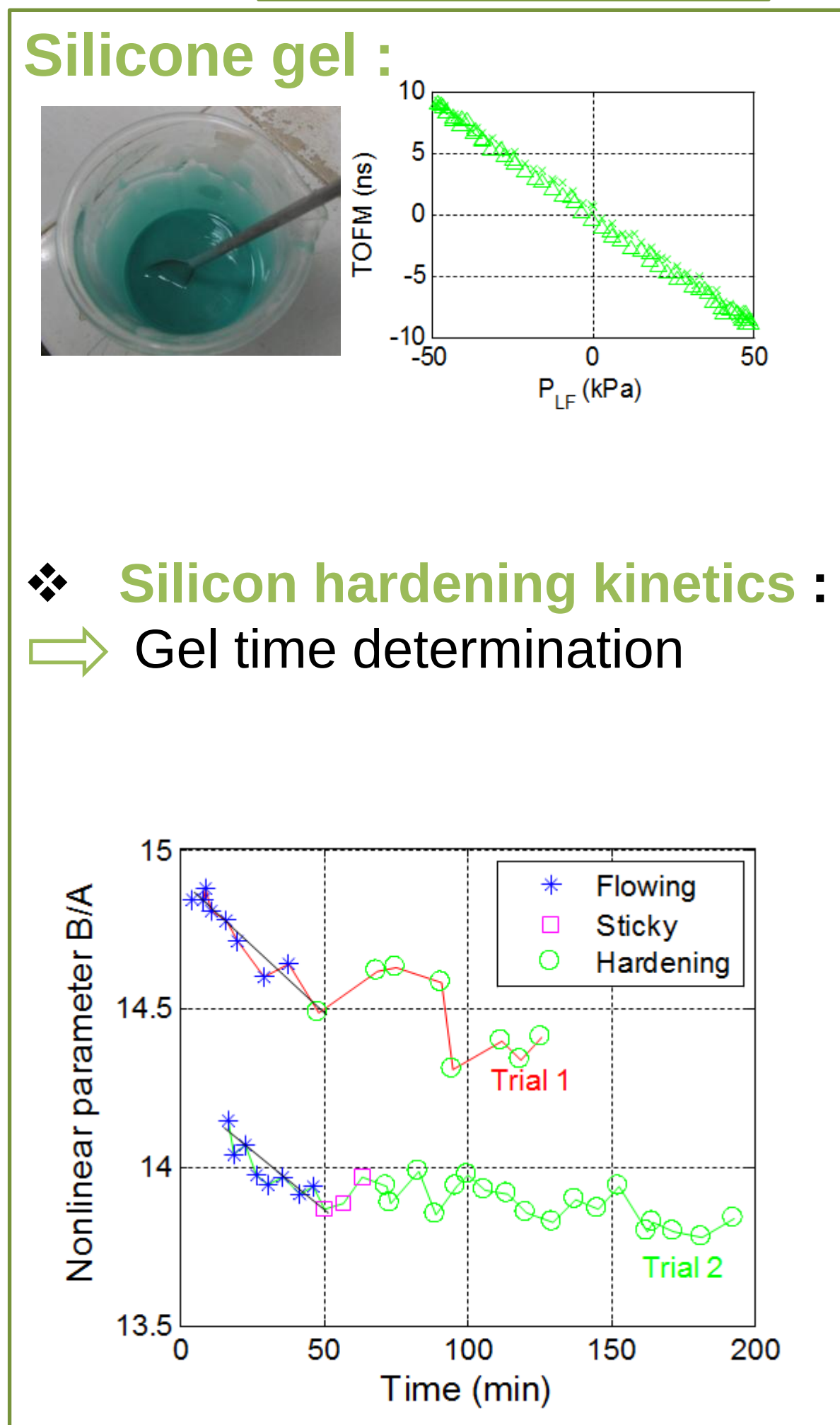
Validation in Fluids

HOMOGENEOUS MEDIA



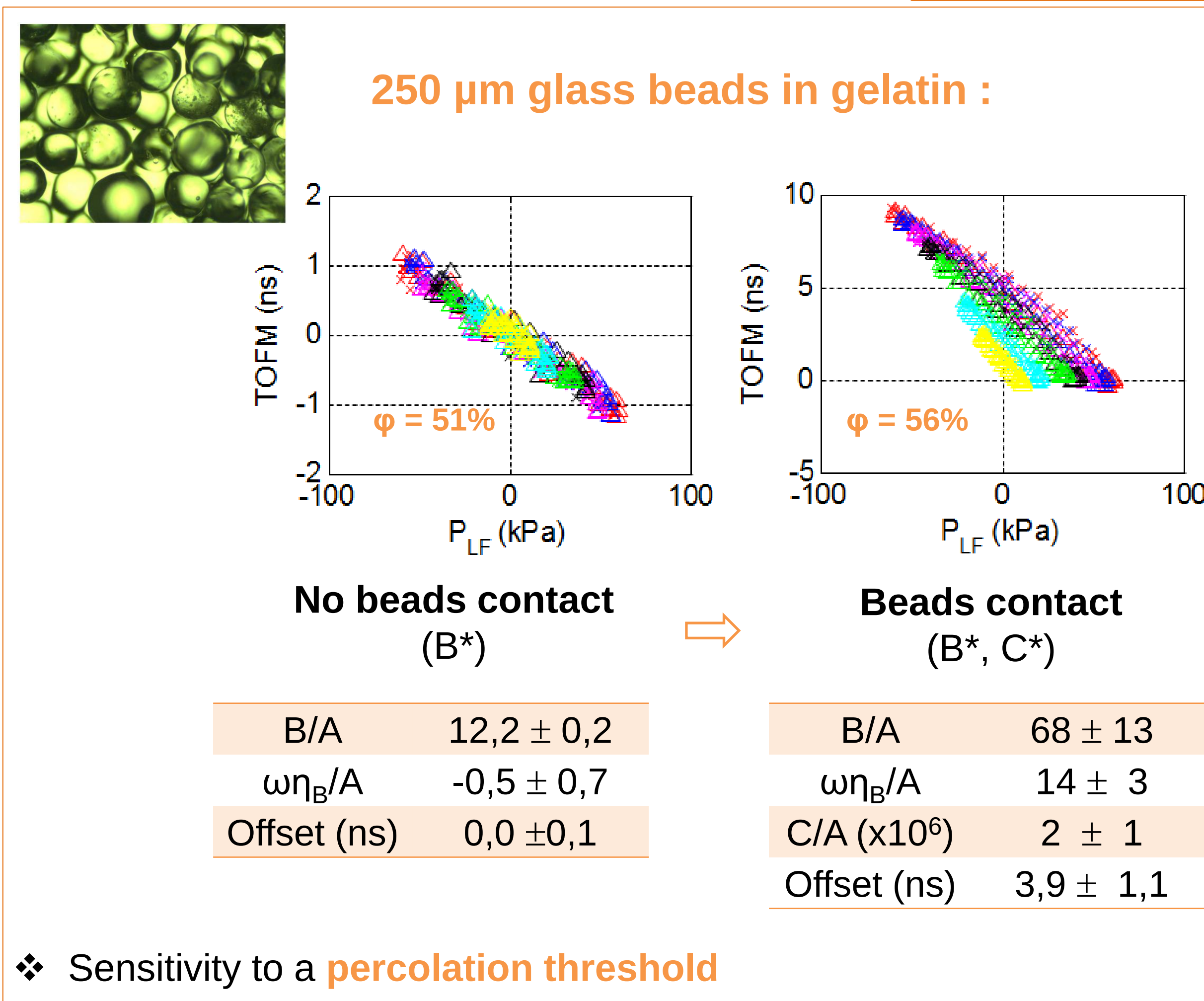
Results in Complex media

POLYMERIZATION



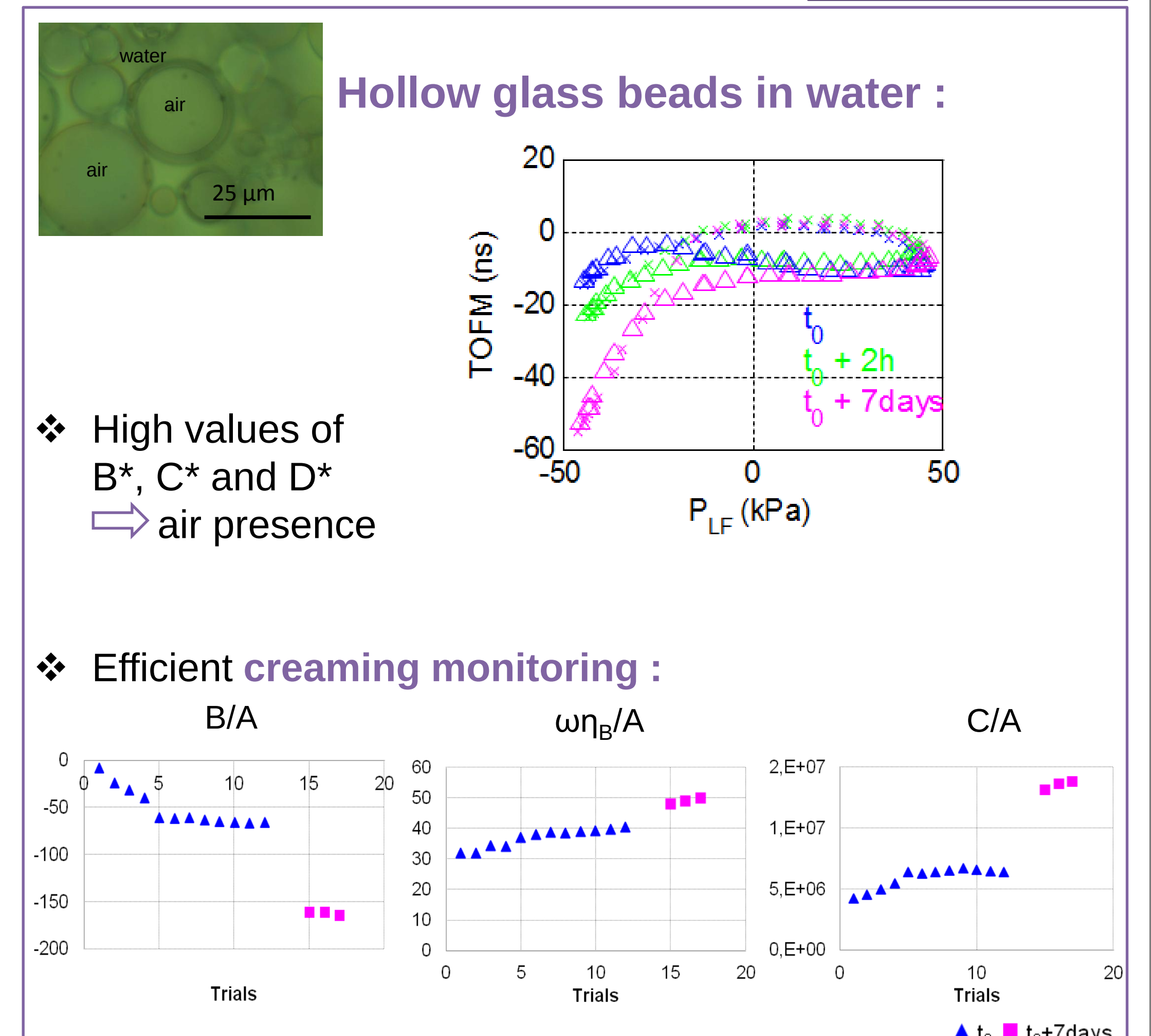
Governed by chemical bonds

GRANULAR MEDIA



Governed by beads contact

AIR-BASED MEDIA



Governed by air and beads contact

Conclusion and perspectives

- ❖ The DAET method measures with a good reproducibility the variations of the bulk viscoelastic modulus, through the quantification of nonlinear elastic and viscous parameters.
- ❖ Homogeneous fluids exhibit classical viscoelastic nonlinearities (1st order B^*) and complex media nonclassical viscoelastic nonlinearities (until 3 orders B^* , C^* , D^*).
- ❖ This method appears to be an interesting alternative to conventional rheometry, especially for the characterization of these complex fluids.
- ❖ A similar work has to be done on the RAM data related to an attenuation of US pulses (thanks to a nonlinear Kramers-Kronig relationship ?...)